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Marshall Space Flight Center
Non-Contact Temperature Measurement Requirements

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The Marshall Space Flight Center is involved with levitation experiments for Spacelab, Space Station, and drop tube/tower operations. These experiments have temperature measurement requirements, that of course must be non-contact in nature. The experiment modules involved are the Acoustic Levitator Furnace(ALF), and the Modular Electromagnetic Levitator(MEL). User requirements for the MEL are being covered separately, and will not be covered here. This paper will focus on user requirements of the ALF and drop tube. The center also has temperature measurement needs that are not microgravity experiment oriented, but rather are related to the propulsion system for the STS. This requirement will also be discussed.

The research objective of the ALF is to quantify the extent of enhancement of glass formation under containerless low-g conditions. Each experiment will involve the containerless melting and resolidification of a glass forming composition several times at numerous cooling rates. A typical experiment would involve 5 to 10 samples, melted and cooled at 5 to 10 different cooling rates ranging from 0.1°C/sec to 20°C/sec. This cooling rate range is based on Ga_2O_3-43CaO. Secondary experiments will include determination of the maximum quench rate possible, and rates as high as 250°C/sec will be attempted. A typical experiment timeline is outlined in figure 1. Figure 2 illustrates a hypothetical scenario in which it is discovered that glass formation is greatly enhanced under microgravity conditions.

The temperature of the ALF furnace will range from 400 to 1750°C, with temperature control accuracy of $\pm$ 3°C. The sample heating rate will be at least 2°C/sec, with higher rates preferred. The furnace atmospheres are nitrogen,, argon, oxygen, and mixtures of these gases.

For the critical glass formation experiment, the knowledge of the time and temperature of nucleation and crystallization is crucial. Thermocouples placed near the sample could provide near real temperature data at slow cooling rates. At higher cooling rates however, where thermal models are not as valid, radiation pyrometry will be necessary to determine the actual sample temperature. The pyrometer should operate at a wavelength that is opaque to the sample to prevent problems with variable emissivity of semitransparent materials. Refractory oxides are generally transparent at visible and near infrared wavelengths. A calibration curve for the

optical pyrometer could be obtained by running one sample with a thermocouple embedded in the sample.

Two pyrometry systems are planned for the ALF, thermal imaging pyrometry and single spot optical pyrometry. The thermal image pyrometer assumes black body conditions, and calibration will be accomplished by sample temperature measurement in duplicate flight hardware. This system will provide two orthogonal views of the sample, operate at visible wavelength, and have a temperature resolution of 1^{o}. The absolute accuracy, assuming black body conditions, will be $\pm 5^{o}C$. The nominal measurement rate is 1/sec, with a fast burst rate of 10/sec for 1 second.

The single spot system will provide two orthogonal views. The wavelength will be sample dependent, but will be greater than 4.5 um. Resolution will be $1^{o}C$, which is acceptable in the temperature range of 400 to $1750^{o}C$. The measurement rate will be up to 100/sec.

Required digital data will include process identification, sample number, processing time, furnace thermocouple temperatures, noncontact sample temperature, heating/cooling rates, gas quench flow rates, acoustic power levels, and acoustic phase information.

The drop tube is a facility at MSFC in which samples are dropped to simulate micro-g. The drop tube is 350-feet-long and samples fall in vacuum for 4.6 seconds. There are view ports every 24 feet along the length of the tube. The drops are typically opaque metallic samples filled with a gas. The gases are helium, argon, air, or mixtures of helium/hydrogen or air/hydrogen. Typically, the drop tube is run with a vacuum of 10^{-6} Torr or with a helium atmosphere with up to 6% hydrogen.

In drop tube experiments at MSFC, noncontact temperature measurements of the falling drops are required in order to determine undercooling and solidification process parameters. The drops are levitated and melted at the top of the drop tube facility. Since it is important to know the complete thermal history of the drop, the temperature is measured to determine how far above the melting point of the material it was heated, and at what temperature the drop is released. Then temperature measurements are required of the drop as it undercools during its fall and during recalescence.

The ideal instrument to measure the temperatures at the drop tube facility would have a measurement range of 800 to $3000^{o}C$ with a resolution of 1^{o} C. The optimum measurement rate would be 10^{5} readings/sec.

In the propulsion area at MSFC there is a need for noncontact temperature measurement of the spatial and temporal surfaces of Space Shuttle Main Engine turbine blades for thermal model verifications. Contact measurement would interrupt the blade boundary layer, changing heat transfer rates.

These blades rotate at 600 revolutions per second, and have an initial acceleration of 600 revolutions/sec/sec. The blade environment will consist of a mixture of hydrogen and steam, but could also be locally oxygen rich during transient conditions. Steady state temperatures will range from 1000^{o}Rto 2000^{o}R. Transient temperatures could range between 500 and 6000^{o}R. Transient measurements should be continuous over 10 seconds. The required precision would be ± 10 to $\pm 50^{o}$R depending on the thermal phase for model validation. The spatial resolution required is 0.2 inches.

For modeling and verification in propulsion research, confirming gas temperatures as well as those of components is necessary. This would be required in laboratory setting as well as in operating size systems. Temperature measurement is required for the solid propellant at room temperature to combustion products at steady state, from ambient pressure to 1200 psia.

The solid propellants burn around 6000^{o}R, and the hybrids(usually solid fuel with liquid oxidizer) burn in the low 7000^{o}R range. In past experiments thermocouples have melted after 4000^{o}R, and the adhesives used for the thermocouples have melted at 400^{o}R. Inserting probes into surrounding hardware has been attemped, but these probes also melted around 4500^{o}R.

A typical combustion experiment would have a maximum burn time of 60 seconds. Measurements required include pressure, temperature, flowrate, and visual observation. For rocket plume measurements a spatial resolution of one percent for 10, 100, and 1000 micron and 10, 100, and 500 mm fields of view is required. Noncontact temperature measurement at these high temperatures is also needed for materials characterization studies for future generation booster systems.

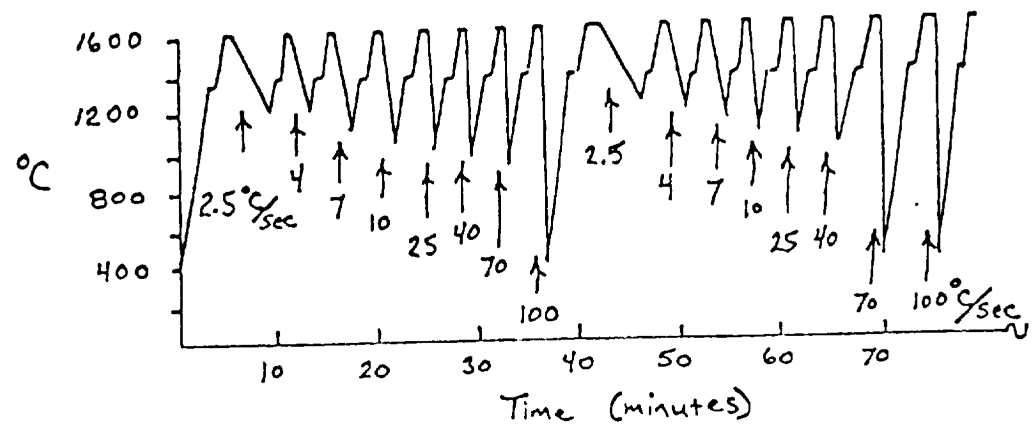
Effective noncontact temperature measurement techniques at high temperatures can therefore benefit not only the microgravity materials science disciplines, but propulsion technology as well. Those techniques developed for microgravity science may at some point be adapted to use for other technologies.

Typical Flight Experiment Timeline

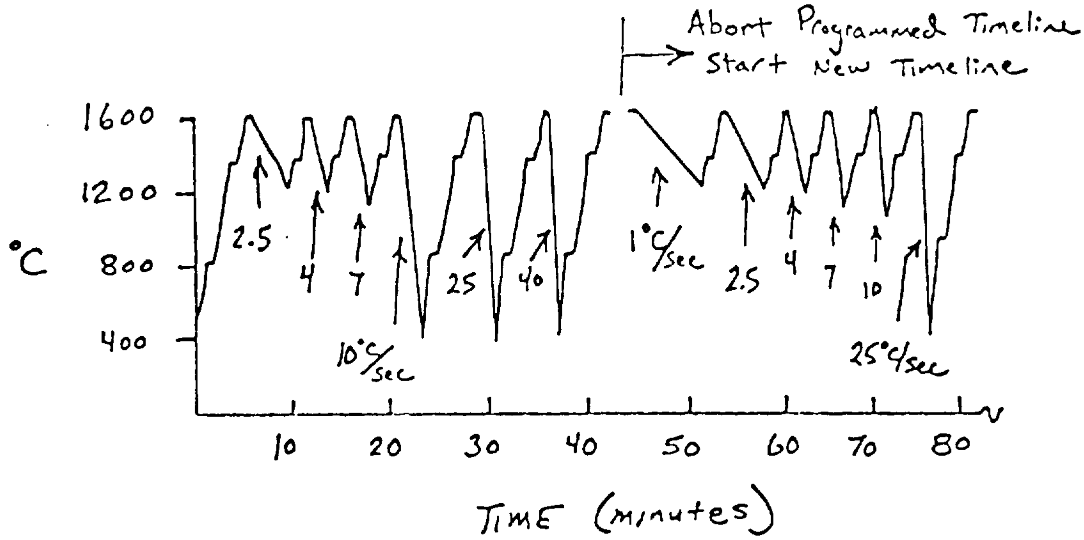
A typical hypothetical timeline for a glass formation space experiment using a reluctant glass former is shown in Figure 3 and can be summarized as follows:

1. Deploy the sample into the "cold" 400^{o}C furnace. Initiate data collection including furnace temperature and sample temperatures at a rate of about 1 reading per second. Record the image with video having a minimum frame rate of one frame per second to verify the maintaining of containerless conditions.
2. Heat at specified heating rate (ie. 4^{o}C/sec, 400 to 800^{o}C, 100 sec).
3. Observe crystallization time and temperature. Video will confirm glass crystallization on heating.
4. Continue heating, past melting (which can serve as an independent temperature calibration point) to soak temperature (800 to 1600^{o}C, 200 sec). Video sampling to confirm sample melting and containerless conditions.
5. Soak for 1 min. above critical temperature (60 sec).
6. Initiate cooling cycle. Quench at cooling rates ranging from 0.1^{o}C/sec to 20^{o}C/sec (faster cooling rates to 250^{o}C/sec will be tested). Start rapid data collection (i.e. sample temperature at 1000 readings per sec.). Determine whether the sample crystallized or formed a glass from the thermal data (presence or absence of recalescence). Obtain time and temperature of crystallization from thermal data. Video is required to confirm the presence or absence of crystallization (High resolution video is desirable).
7. Either retrieve the sample or recycle the same sample again.
8. For a given sample composition perform at least 5 runs at a given cooling rate, perform 5 to 10 different cooling rates.

Figure 1



TYPICAL EXPERIMENTAL TIMELINE
HYPOTHETICAL DATA



TYPICAL EXPERIMENTAL TIMELINE, DIFFERENT HYPOTHETICAL DATA
WITH ENHANCED GLASS FORMATION, SHOWING CHANGE IN TIMELINE.

Figure 2 illustrates a second hypothetical scenario in which it is discovered that glass formation is greatly enhanced by low-g containerless processing at particular cooling rates. Telescience will allow the changing of the experimental protocol to concentrate experiments within the more useful cooling rates in order to maximize the significance of data output. In this case after a number of glass formation experiments are performed, nucleation data would be more beneficial. Effective use of telescience could greatly enhance the significance of data by concentrating on cooling rates that yield the most appropriate kinds of data.

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